Monolithic bandpass RC-CR filter for high energy physics experiments

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A monolithic implementation of a bandpass filter featuring equal (low and high) coupling time constants (RC-CR filter) of 20ns is proposed. The circuit satisfies the requirements of the forthcoming high energy physics experiments at the CERN laboratory: high speed, large dynamic range, low power consumption and 50Ω coaxial cable driving capability. Moreover optimized noise performance is obtained. The design exploiting the repetitive use of a very simple cell with high open loop gain and large frequency bandwidth allows an analogue sum to be efficiently realized.

Introduction: Future colliders such as LHCs (large hadron colliders) at CERN Labs will be able to generate very high energy particles at high rates: the detectors of these events and the front-end electronics will need to be very fast, with a dynamic range of ~100DB. Because large signals are expected, the overall electronic chain gain (a preamplifier and a filter [I, 2]) must be small. This implies that the noise contribution of the stages following the preamplifier must be taken into account. In this Letter a simple solution for the design of a very fast filtering section with good noise performance is described. The proposed modular solution also allows an analogue sum to be efficiently realized as required in many of these applications.

System description: The overall front-end structure is shown in Fig. 1. The detector is modelled with a capacitance $C_p$ shunted by a b-like unipolar signal current ($I_{IN} = Q(t)$), generated by the impinging particle, which is first integrated by the charge sensitive preamplifier $A_1$ [3]. The transfer function from $I_{IN}$ to $v_f$ (at the receiving end of a 50Ω coaxial cable) is $v_f / I_{IN} = R_f / (2\pi C_f R_f + 1)$. This signal is then filtered using a differentiator followed by an integrator (RC-CR filter). The RC-CR bandpass transfer function is $\pi(1 + s\tau)$, and the output $v_{out}$ due to $I_{IN} = Q(t)$ is

$$v_{out} = \frac{Q}{2\pi CF RF (1 + s\tau)^2}$$

with $\tau = (RC_f + R_fR_p)C_f$, $R_f \gg R_p$, and $R_f \gg \tau$. To compute the total output noise of the chain only the white noise generators indicated in Fig. 1 are considered: this is a good approximation if the filtering time constant $\tau$ is very small, as in the case at LHC where $\tau = 20ns$. Using input bipolar transistors, the input referred noise of each of the two amplifiers in the chain is given by

$$v_{n,bias,IN} = 4kT/R_{n,th}$$

where $R_{n,th} = R_{n,base} + (1/2qV_T)$. $V_T$ is the absolute temperature, $R_{n,base}$ is the Boltzmann constant, and $R_{n,base}$ and $g_{m,th}$ are the base spreading resistance and the transconductance, respectively, of the input devices of $A_1$ (2). The generators $v_{n,bias,IN} = 4kT/R_{n,th}R_{n,th}$ account for the thermal noise of resistors $R_{n,base}$ and $R_{n,th}$. By neglecting, as a first approximation, the input capacitance of $A_1 (A2)$ and the output buffer noise contribution, the total root mean square (RMS) output noise is

$$V_{n,RMS} = \frac{R_f}{RF} R_f = \frac{1}{8\pi} \left[ \frac{C_D + C_F}{C_F} \right] ^2 \left( \frac{C_D}{C_F} \right)^2 + \left( \frac{C_F}{C_F} \right)^2 + \left( \frac{C_D}{C_D} \right)^2$$

From eqn. 1 the noise contributed by the second amplifier ($v_f$) to the overall output noise can be significant especially if the gain of the filter $R_f R_p$ is close to 1. In such a case in fact, both terms of eqn. 1 have comparable coefficients. The proposed solution configures in a simple way the filter of Fig. 1, with a configuration that reduces the relative importance of the noise due to the second amplifier ($v_f$).

Filter design: The design of the filter exploits the fact that the closed loop gain must be large (because of the expected large input signal), enabling the use of few transistors for realizing the amplifier. The proposed bandpass filter is shown in Fig. 2. $Q_1$ operates at a constant current and the structure made up of $Q_1$ and $Q_2$ operates as a voltage buffer (from $v_{IN}$ to $v_{OUT}$) with a very high input impedance ($R_{in}$). The voltage gain from the input ($v_{IN}$) to node $D$ ($v_{OUT}$), very close to unity, is given by

$$V_{OUT} = \frac{1}{1 + \alpha R_{n,th} g_{m,th} \alpha R_{n,th}}$$

The input impedance at the emitter of $Q1$ is equal to $R_{in} = (1 + \alpha R_{n,th} g_{m,th} \alpha R_{n,th})$, which assumes a very large value. As an example, $R_{in} = 500k\Omega$, $I_{IN} = 0.2mA$, and $\alpha = 0.5$, results in $R_{in} = 200k\Omega$ and $v_{OUT} \approx 0.9995$. The voltage gain from $v_{IN}$ to the collector of $Q2$ in Fig. 2 equals $-1/(1 + \alpha R_{n,th} g_{m,th} \alpha R_{n,th})$; the use of the $Q2$-Q3 Darlington configuration reduces the error due to the $\beta$ effect from $1/\beta$ to $1/\beta^2$. The bandwidth of the amplifying network is very large, of the order of the $\beta$ of the output transistor if the Miller effect of the output transistor is kept low, and proper biasing current is adjusted for $Q1$ and $Q2$. The proposed cell is also used as a unity gain buffer in the output stage, made up of $Q4$, $Q5$ and $Q6$. The feedback action of $Q4$ lowers the output impedance of $Q5$, $Q6$ from $1/(g_{m,th} R_{n,th})$ to $-1/(g_{m,th} R_{n,th})$. The impedance at the emitter of $Q4$ and $Q6$ (the impedance at the Q4 collector). The output preamp buffer is able to drive a terminated 50Ω coaxial cable.

An important result regards the total RMS output noise which is now given by

$$V_{n,RMS} = \frac{R_f}{RF} R_f = \frac{1}{8\pi} \left[ \frac{C_D + C_F}{C_F} \right] ^2 \left( \frac{C_D}{C_F} \right)^2 + \left( \frac{C_F}{C_F} \right)^2 + \left( \frac{C_D}{C_D} \right)^2$$

$$+ \frac{1}{8\pi} \left( \frac{C_D}{C_D} \right)^2$$

(2)

It can be seen that in eqn. 2 the contribution of the series noise of the filter, ($v_f$), to the total output noise is reduced with respect to eqn. 1 (comparing the last term of eqns. 1 and 2). This circuit is very attractive when it is necessary to sum the signals coming from several detectors [4] in order to reduce the number of cable connections. The implementation of the sum is shown in Fig. 3. The scheme is based on the use of many input cells like that described in Fig. 2. In addition this arrangement permits area to be saved by sharing the filtering capacitance, $C_p$, between all the input cells.

Simulated results: Both the networks of Figs. 2 and 3 have been simulated using models corresponding to a BICMOS technology (HF22CMOS from SGS-Thomson) which features bipolar transistors with $f_T = 6GHz$ and $g_{m,th}$ with $f_T = 2GHz$. For the intended applications ($\tau = 20ns$) the component sizes are: $R_f = 300\Omega$, $C_p = 66pF$, $R_p = 700\Omega$, $C_p = 28pF$. In Fig. 4 the simulated responses to small (left) and large (right) step input signals are shown, when the load is 100Ω (assuming to drive a terminated 50Ω coaxial cable). The linearity error for an output signal amplitude up to 5V is always
when four channels are added at the filter input.

-2nV/√Hz, limited by the 300Ω capacitance lower than 0.5%. The input noise of the filter of Fig. 2 is improving the noise performance. Power dissipation is -30mW.

Four signals are considered, the power dissipation is only 30mW. Very low input noise and large dynamic range (-110dB for experiment with a very large number of channels at CERN Labs.

The network exploits the repetitive use of a simple configuration with large open loop gain and frequency bandwidth, which allows us also to sum many input signals. When the summing of four signals is considered, the power dissipation is only 30mW. Very low input noise (2nV/√Hz) and large dynamic range (-110dB for experiment with a very large number of channels at CERN Labs.

Conclusions: A very fast bandpass RC-CR filter (t = 20ns) has been designed for high energy physics application. The network exploits the repetitive use of a simple configuration with large open loop gain and frequency bandwidth, which allows us also to sum many input signals. When the summing of four signals is considered, the power dissipation is only 30mW. Very low input noise (2nV/√Hz) and large dynamic range (-110dB for experiment with a very large number of channels at CERN Labs.

The network has a simpler architecture compared with existing approaches, while retaining reasonable performance.

Preprocessing network for separating multiple binary image objects

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A network is described for separating binary image objects from the background, to be used as a preprocessor for a recognition network which assumes that only one object is present in the image plane. The network has a simpler architecture compared with existing approaches, while retaining reasonable performance.

Introduction: The design of neural networks for image object recognition is typically based on the assumption that only one object is present in the image plane. A preprocessor is required to select one object at a time for recognition. Several approaches have been presented for implementing this preprocessor in a network architecture [2-4]. Although capable of processing multiple objects, these approaches involve complicated network architectures that are difficult to simplify for application to binary images. Therefore, we propose a new preprocessor network, with a simple architecture, providing rapid object selection.

Proposed preprocessing network: Our object detection approach is based on region growing [1], which is commonly used in image segmentation. This leads to a simple network architecture which provides good object selection performance. To emphasise the basic concept of our approach, we use precomputed connection weights to meet our specific requirements, as opposed to providing trainable connection weights.

The proposed architecture has two parts: the growing network and the attention network, as shown in Fig. 1, where the growing network expands a region encompassing an object from a seed and produces an image containing just that object at the output. The attention network produces seeds through the use of correlation operations to initiate the growing process.

Growing network: The growing network consists of three layers: growing, memory, and inhibiting. The growing layer implements 'region growing', producing an image containing only the current object, and the memory and inhibiting layers mask off previously detected objects.

The input binary image is first masked by the inhibiting layer, having the characteristic

\[ i(x, y, t) = \begin{cases} f(x, y) & \text{if } m(x, y, t) = 0 \\ 0 & \text{if } m(x, y, t) = 1 \end{cases} \]  

where \( m(x, y, t) \) is the output of the memory layer.

The growing layer, with connections shown in Fig. 2, has the characteristic

\[ g(x, y, t + \Delta t) = \begin{cases} 1 & \text{if } s(x, y, t) \geq 0 \\ 0 & \text{otherwise} \end{cases} \]

where

\[ s(x, y, t) = 0.8 \cdot i(x, y, t) + 0.3 \cdot a(x, y, t) + 0.3 \cdot g(x - 1, y, t) + 0.3 \cdot g(x + 1, y, t) + 0.3 \cdot g(x + 1, y + 1, t) + 0.3 \cdot g(x, y - 1, t) - 2.0 \cdot r(t) - 1.0 \]